The Regional Transport of Point and Nonpoint-Source Nitrogen to the Gulf of Mexico

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Abstract

The quantification of the regional transport of nutrients to the Gulf of Mexico is important to developing management strategies for reducing the hypoxic zone observed in recent summers on the Louisiana coastal shelf. Although existing research clearly identifies the Mississippi and Atchafalaya Rivers as the primary conduits for nutrients, the origin (type and location) of the sources of nutrients in these rivers is less certain. Better estimates of the quantities of point- and nonpoint-source nutrients delivered to the Gulf of Mexico from interior watersheds could improve the efficiency of management strategies.

To assist in identifying the origin of stream nutrients nationally, we developed a water-quality model of nutrient flux in rivers of the United States. This model allows us to estimate the origin of point and nonpoint source nutrient flux at numerous locations on the coastal margin including the outlets of the Mississippi and Atchafalaya Rivers. The regression-based water-quality model relates monitored nutrient flux from 430 watersheds to various measures of upstream pollutant loadings, such as industrial and municipal discharges, fertilizer application, animal manure, and atmospheric deposition. The monitored watersheds range in size from several hundred to several tens of thousands of square miles. Flux estimates are developed from regularly-collected season nutrient measurements and daily estimates of streamflow using log-regression rating curve techniques. The estimated loadings of nonpoint-source nutrients to streams include the effects of watershed physical characteristics including precipitation, soil permeability, and topography. The model also estimates the first-order decay of nutrients during the transport of point and nonpoint sources through a digital stream network of nearly one million kilometers and 60,000 reaches. These decay rates reflect time-of-travel estimates from field studies and the residence time of water in major reservoirs.Through application of the model to unmonitored reaches, we estimate the quantities of point and nonpoint source nutrients delivered to the Gulf from several interior watersheds of the Mississippi and Atchafalaya Basins, including the Missouri, Arkansas, Upper Mississippi, and Ohio River Basins. All model predictions are accompanied by estimates of statistical error.

Introduction

In recent summers, a large area of very low dissolved oxygen concentrations (i.e., the hypoxic or "dead" zone) has appeared on the Louisiana coastal shelf (Rabalais and others, 1994). Although researchers have observed linkages between the nutrient-enriched waters of the Mississippi and Atchafalaya Rivers and spatial and temporal variations in the hypoxic zone (e.g., Rabalais and others, 1994; Justic and others, 1993), the origin of nutrients in these rivers is uncertain. The development of efficient management strategies for reducing the hypoxic zone depends on better estimates of the point and nonpoint-source nutrients delivered to the Gulf from interior watersheds of these rivers.

We developed a water-quality model of nutrient flux in rivers of the United States to assist in quantifying the origin of stream nutrients nationally. This model allows us to estimate the origin of point- and nonpoint-source nutrient flux at numerous locations on the coastal margin including the outlet of the Mississippi River. The regression-based water quality model relates monitored total nitrogen flux from 430 watersheds to various measures of upstream pollutant loadings, including industrial and municipal treatment plant discharges, fertilizer application, animal manure, and atmospheric deposition (R2= 0.83). The monitored watersheds range in size from several hundred to several tens of thousands of square miles. Mean estimates of flux for the period 1985-88 were computed from regularly-collected seasonal nutrient measurements and daily estimates of streamflow using log-regression rating curve techniques. The estimated loadings of nonpoint-source nutrients to streams include the effects of watershed physical characteristics including precipitation, soil permeability, and topography. The model also estimates the first-order decay of nutrients during the transport of point and nonpoint sources through a digital stream network of nearly one million kilometers and 60,000 reaches. These decay rates reflect time-of-travel estimates from field studies and the residence time of water in major reservoirs.

Through application of the model to the Mississippi River and its tributaries, we estimated the quantities of total nitrogen delivered to the Gulf from several interior watersheds including the Missouri, Ohio, White / Red, and the Upper, Central, and Lower Mississippi River Basins (Figure 74). These estimates indicate that more than 70 percent of the total nitrogen delivered to the Gulf by the Mississippi River originates above the confluence of the Ohio and Mississippi Rivers. This nitrogen is transported over distances of more than 1000 miles. The Upper and Central Mississippi Basins, which include portions of the states of Minnesota, Wisconsin, Iowa, Missouri, and Illinois, account for the largest quantity of nitrogen (39 percent) delivered to the Gulf. Smaller fractions originate in the Ohio (22 percent) and the Missouri (11 percent) River Basins. Downstream from the Mississippi / Ohio River confluence, the Lower Mississippi Basin, which drains portions of the states of Tennessee, Arkansas, Missouri, Mississippi, and Louisiana, contributes nearly a quarter of the nitrogen to the Gulf, whereas the White / Arkansas River Basins contribute six percent of the nitrogen.

The development of economically efficient nitrogen removal strategies in the Mississippi River Basin requires consideration of many factors, including the benefits (i.e., nitrogen reductions) expected from the application of controls in different interior watersheds. Estimates of each watershed's contribution of nitrogen to the Gulf per unit of drainage area (i.e., yield; see Figure 75) may be used to approximate the level of benefits to the Gulf expected per unit of drainage area receiving controls. Accordingly, the largest benefits to the Gulf per unit area controlled would be expected from nutrient controls applied in the Lower, Central, and Upper Mississippi River Basins where per unit area nitrogen contributions exceed those in the Ohio, White / Arkansas, and Missouri Basins by more than a factor of two.

Although the Lower Mississippi Basin accounts for less than 25 percent of the Mississippi River's nitrogen contribution to the Gulf, the benefits of nutrient controls in this basin would be expected to be more than twice as large as those in other watersheds. The large per unit area nitrogen contribution from the Lower Mississippi Basin (Figure 75) reflects the comparatively small drainage area of the basin and its proximity to the Gulf which lead to fewer losses of nitrogen.

In applying the nutrient model, we separately tracked the contributions of point and nonpoint sources of stream nitrogen to the Gulf. On the basis of these analyses, we estimate that approximately 90 percent of the nitrogen delivered to the Gulf by the Mississippi River originates from nonpoint sources consisting predominantly of nitrogen in agricultural runoff and atmospheric deposition. More detailed applications of the nutrient model will be needed to resolve the relative importance of these two sources. Only about one percent of the nitrogen comes from point sources in the effluent of municipal treatment plants and industries. The remaining nitrogen delivered to the Gulf (9 percent) is from unknown sources as estimated by the intercept of the regression model. These unspecified sources may potentially include inputs of nitrogen from ground water.

References

Justic, D., Rabalais, N.N., Turner, E.R., and Wiseman, W.J., 1993, Seasonal Coupling Between Riverborne Nutrients, Net Productivity and Hypoxia, Marine Pollution Bulletin, v. 26, no. 4, pp. 184-189.

Rabalais, N.N., Turner, R.E., Wiseman, W.J., Justic, D., Dortch, Q., and Gupta, B.S., 1994, Hypoxia on the Louisiana Shelf and System Responses to Nutrient Changes in the Mississippi River: A Brief Synopsis, in National Oceanic and Atmospheric Administration, Nutrient-Enhanced Coastal Ocean Productivity, Proceedings of the 1994 Synthesis Workshop, Baton, Rouge, Louisiana.

Total Nitrogen Flux to the Gulf of Mexico from Interior Watersheds of the Mississippi River Basin Standardized for Drainage Basin Size

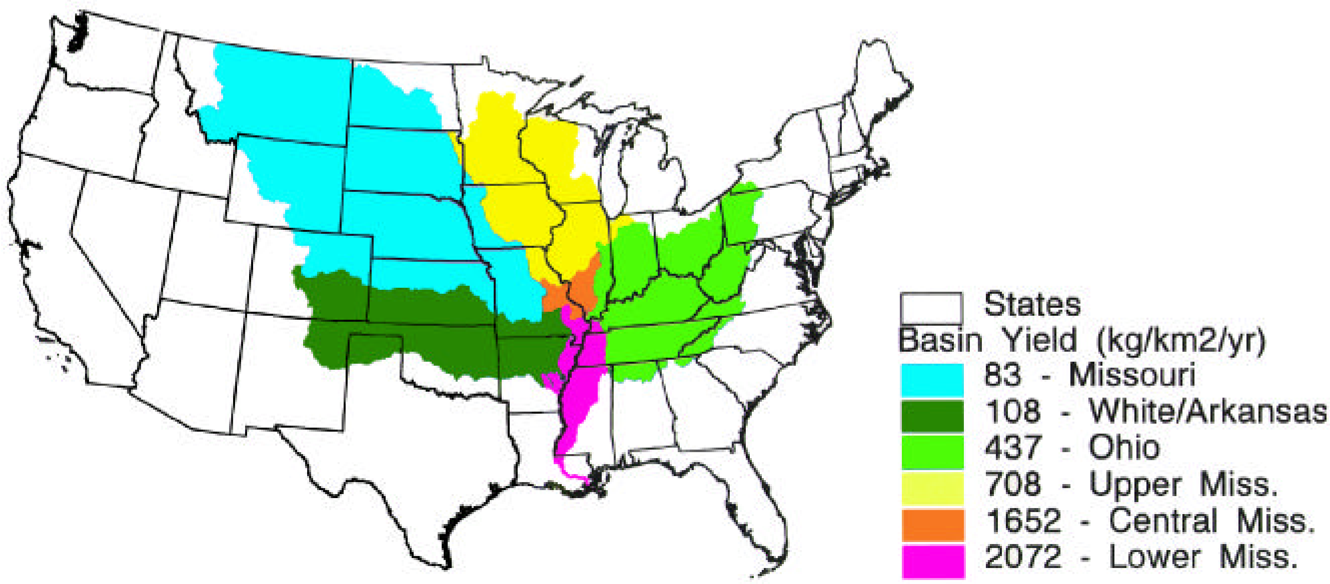

Figure 74.

The U.S. Geological survey recently estimated the quantities of total nitrogen delivered to the Gulf of Mexico from several interior watersheds of the Mississippi River. These estimates, based on river monitoring data and a regression-based water-quality model, indicate that more than 70 percent of the nitrogen originates above the confluence of the Ohio and Mississippi Rivers and is transported over distances of more than 1000 miles. Downstream from the Mississippi/Ohio River confluence, the Lower Mississippi and the White/Arkansas River Basins contribute nearly 30 percent of the nitrogen. Model estimates also indicate that approximately 90 percent of the nitrogen delivered to the Gulf by the Mississippi River originates from nonpoint sources. Of the remaining nitrogen, one percent is from point sources and nine percent is from unknown sources.

Percentage of the Mississippi River Total Nitrogen Flux to the Gulf of Mexico from Interior Basins

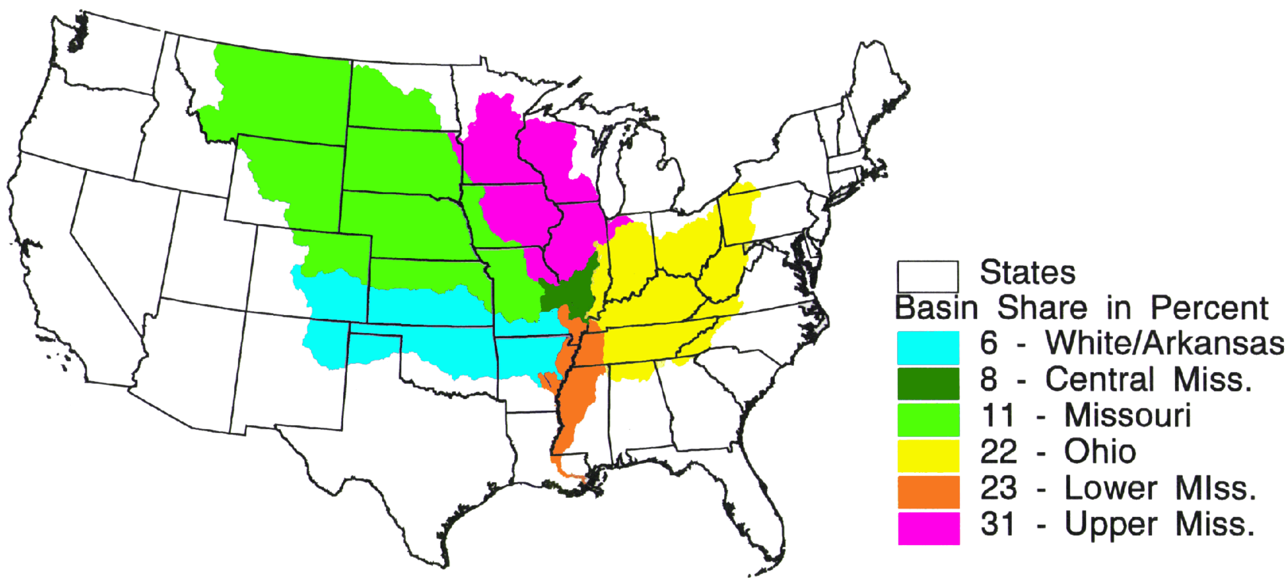

Figure 75.

Estimates of the quantities of total nitrogen delivered to the Gulf of Mexico from several interior watersheds of the Mississippi River per unit of drainage area (kilograms/square kilometer/year) can be used to approximate the level of benefits (i.e., nitrogen reductions) to the Gulf expected per unit of drainage area receiving controls. Developing economically efficient nitrogen removal strategies in the Mississippi Basin requires consideration of many factors, including the benefits expected from the application of controls in different interior watersheds. The largest benefits to the Gulf per unit area controlled would be expected from nutrient controls applied in the Lower, Central, and Upper Mississippi River Basins where per unit area nitrogen contributions exceed those in the Ohio, White/Arkansas, and Missouri Basins by more than a factor of two. Although the Lower Mississippi Basin accounts for less than 25 percent of the Mississippi River's nitrogen contribution to the Gulf (see Figure 74), the benefits of nutrient controls in this basin would be expected to be more than twice as large as those in other watersheds due in part to the Lower Mississippi Basin's proximity to the Gulf.

Presentation Discussion

Richard Alexander (U.S. Geological Survey—Reston, VA)

Fred Bryan *(National Biological Survey/ LSU)* asked if the value Richard Alexander presented for Nitrogen contribution to the river load by the Mississippi River Basin represented a cumulative value or had the contribution of the rest of the watershed been subtracted.

He also speculated that the relative contribution of point and nonpoint source loadings in the lower basin could be estimated by examining the Red-Atchafalaya River System. Most of the point sources in the lower basin are in the industrial corridor between Baton Rouge and New Orleans. Only three or four point sources from Alexandria are in the Red-Atchafalaya system and since the Atchafalaya is 70 percent Mississippi River water by volume, the nonpoint source load could be estimated by comparing the loading in the Red-Atchafalaya system with the loading in the Mississippi River below New Orleans.

Richard Alexander responded to Fred Bryan's question by saying that 23 percent that he cited for total nitrogen is a net contribution. The Arkansas and White Rivers, as well as the upper basin, are subtracted from that value.

In response to Fred Bryan's comment, Richard Alexander replied that they chose not to look at the Atchafalaya, mainly because they do not have a monitoring station at the outlet that meets the criteria for load estimation. He agreed that it is something that needs to be examined and if they did have a monitoring station there it could be included in the budget and the analysis Fred Bryan referred to could be conducted.